

A Novel Anti-Collision Algorithm for High-Density RFID Tags

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ABSTRACT

In a radio frequency identification (RFID) system, when more than one tag communicates with the reader at the same time, a collision will occur, resulting in the failure of that communication. Many anti-collision algorithms, such as Binary Tree (BT), FSA, and DFSA, have been used in ISO and EPC standards to prevent such a collision. This paper develops a new anti-collision algorithm based on the BT and the DFSA algorithms. Specifically, all tags are divided into many groups using the DSFA algorithm. Then, the tags in each group are identified using the BT algorithm. Results indicate that the proposed algorithm performs better than the existing ones in terms of the number of used time slots (the less the used time slot, the faster the algorithm).

Keywords: Anti-Collision Algorithm, Binary Tree, Dynamic Framed Slotted ALOHA, RFID

1. INTRODUCTION

Radio frequency identification (RFID) is a technology for automated identification. Typically, an RFID system consists of a reader and tags, which communicate with one another via radio frequency waves. Recently, RFID has been widely used in many applications, such as transport systems, electronic ticketing, access control, animal identification, logistics, and supply chain management [1].

In the application, where many tags are present in the reader's field, if more than one tag communicates with the reader at the same time, a collision will occur resulting in the failure of that communication. Thus, each tag has to resend all information to the reader. To prevent this problem, an anti-collision algorithm must be used. Based on the International Standards Organization (ISO) and EPCglobal (EPC), there are 3 types of anti-collision algorithms, namely, binary

tree (BT) [2, 3], Framed Slotted ALOHA (FSA) [2], and Dynamic Framed Slotted ALOHA (DFSA) algorithms [2, 4]. However, these algorithms take a lot of time to identify tags [2].

Many improved anti-collision algorithms have recently been proposed in the literature. For example, Cheng and Jin [2] presented the analysis and simulation of several RFID anti-collision algorithms and partitioning of tags for near-optimum RFID anti-collision performance. Shin and Kim [5] proposed a partitioning technique, which enables a faster accurate estimation on the number of contending tags, and yields much higher throughput against previous non-partitioning approaches. Cho *et al.* [6] proposed an anti-collision algorithm using parity bit (ACPB) in RFID system. The ACPB identifies tags without checking all bits in the tags. Then, the reader uses the parity bit, which is added to the tag's ID number. Clearly, ACPB can reduce the number of the requests from the reader. Thus, it can shorten the time of identifying all tags in the reader's field. In this paper, we propose a novel anti-collision algorithm, which is based on the BT algorithm. The proposed algorithm can estimate the number of tags in the reader's field and identifies all tag faster than the existing anti-collision algorithms.

The rest of this paper is organized as follows. Section 2 briefly describes how BT and DFSA algorithms work. A new anti-collision algorithm is explained in Section 3. Section 4 compares the performance of different anti-collision algorithms. Section 5 analyzes the effect of data collusion in RFID systems. Finally, Section 6 concludes this paper.

2. EXISTING ALGORITHMS

This section briefly describes how BT and DFSA perform because their performances are compared with the proposed anti-collision algorithm.

2.1 Binary Tree

The Binary Tree (BT) algorithm or the Query Tree algorithm [6] divides tags into two groups based on the most significant bit (MSB) of the tag's ID number, which consists only of bits "0" and "1." To search a tag, a dividing process continues adding up the number "0" and "1" into each group, until finding a tag [2, 7, 8]. Note that we consider only the

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case where the tags do not support a random generator in hardware for group selection [9], meaning that the BT algorithm operates on the tag's identification (ID) numbers.

To obtain all tags, the reader begins a search by sending a prefix bit "0" or "1" to all tags and waits for the response. If there is only one response, the reader then can identify that tag. However, if more than one tag responds back at the same time, a collision will occur. In this case, the reader will add another bit ("0" or "1") to a prefix bit and send the new prefix bits to the remaining tags until there is only one response. The reader will do this process until all tags are identified.

To compare the performance of different anti-collision algorithms, we use the required total number of commands sent from the reader to the tag as a criterion. Each command is referred to as one time slot (or, in short, slot). Assuming that each slot uses the same processing time, the algorithm that requires a large number of slots will operate slow.

2.2 Dynamic Framed Slotted ALOHA

Dynamic Framed Slotted ALOHA (DFSA) developed from FSA is utilized in Class 1 Generation 2 of EPC [4]. It divides tags into many groups according to the number of slots specified by a reader. All tags will random the slot number between 0 to the number of slots, and the tags having the same number will be in the same group.

First, the reader sends a command with a "slot-number." Note that the "slot-number" will be set to 0 at the first time, and it will then increase by 1 for every round. If the tag has a group number equal to the "slot-number," that tag will respond to the reader. Then, if there is only one response at this time, the reader will identify that tag. If there is a collision, the reader will increase the "slot-number" by 1 and send it to all remaining tags. The reader repeats this process until the "slot-number" is equal to the number of slots.

When the reader finishes sending a command with the "slot-number" between 0 to the number of slots, we assume that the operation time is one frame. If the reader cannot identify all tags in the reader's field, the reader will begin the new frame. The reader can adjust the number of slots in the new frame based on a Q-parameter [4, 5]. The reader will do this process until it can identify all tags in the reader's field.

3. PROPOSED ALGORITHM

The simulation in [10] showed that the BT algorithm is more efficient than FSA and DFSA. This is because the BT algorithm uses a less number of slots when the number of tags in the system is small. Practically, when the system has a large number of tags, the BT algorithm tends to perform worse because it

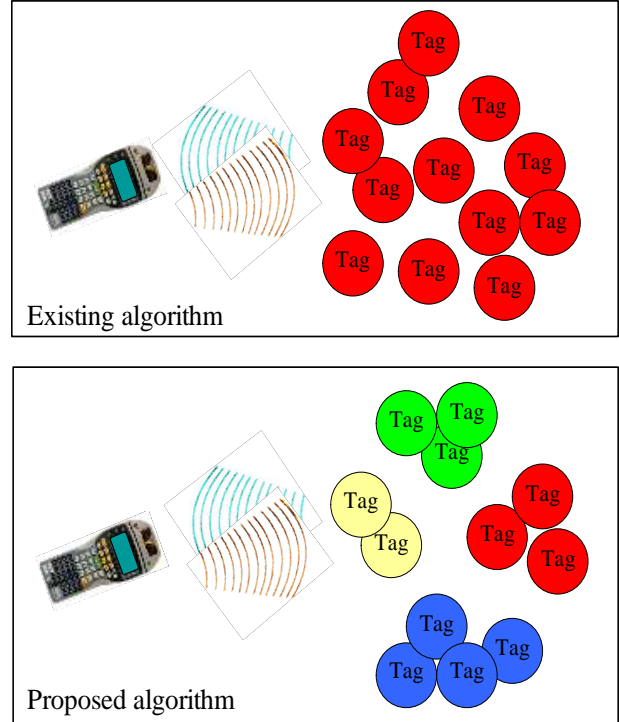


Fig.1: How the proposed algorithm works.

uses a lot of slots to identify all tags if compared to DFSA [10].

The proposed algorithm is developed based on the BT and the DFSA algorithms. We first divide tags into many groups using the DFSA algorithm as illustrated in Fig. 1. Then, all tags in each group are identified using the BT algorithm. To achieve this, we assume that the tag can generate a 9-bit uniform random number and has a function to select a group according to that random number. To make the proposed algorithm more efficient, the number of groups must coincide with the number of tags. Specifically, the less the number of tags, the less the number of groups. Therefore, we must first estimate the number of tags in the reader's field so as to determine the number of groups used in the proposed algorithm. To do this, we use the number of tags in each group to estimate the total number of tags in the reader's field since each group should have an equal probability to have the same number of tags.

Figure 2 shows how the proposed anti-collision algorithm works. First, we determine the estimated number of tags, \hat{T}_{ALL} , in the reader's field. The estimated number of tags will depend on the number of groups that tags are divided. The estimation is calculated from the number of tags within selected groups. Given that the selected groups are chosen to be any three groups for a sample size, the simulation with maximum of 1000 tags suggested that the number of groups suitable for the proposed algorithm is 32 groups. We randomly pick three groups from these 32 groups to identify a number of tags based on the BT

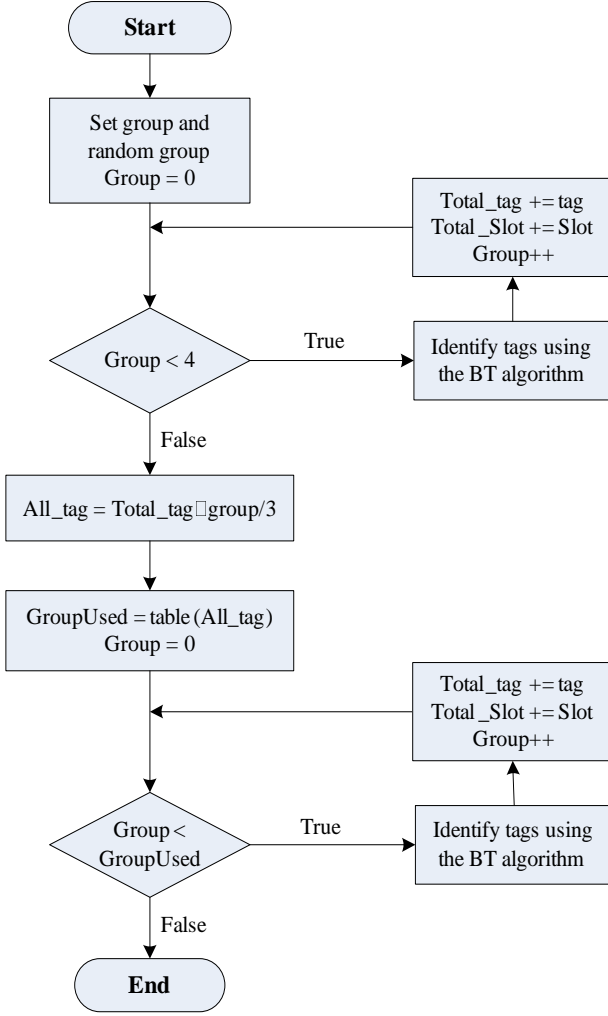


Fig.2: A flowchart of the proposed anti-collision algorithm.

algorithm. Given that three groups are the sample size for all tags in the field, we can now estimate the total number of tags in the reader's fields according to

$$\hat{T}_{ALL} = \frac{T_G N_{ALL}}{N_G} \quad (1)$$

where \hat{T}_{ALL} is the estimated total number of tags in the reader's field, T_G is the number of identified tags in the selected three groups, N_G is the number of selected groups used to find \hat{T}_{ALL} (e.g., $N_G = 3$), and N_{ALL} is the total number of groups in the reader's field (e.g., $N_{ALL} = 32$).

Once we have an estimate of the total number of tags in the reader's field, we can now choose a suitable number of groups to identify tags according to Table 1, which is obtained from extensive simulation search. Then, we use a regular BT algorithm to identify tags in each group.

Table 1: Number of groups for different estimated number of tags.

Estimated number of tags	Number of groups
< 50	16
< 100	32
< 200	64
< 400	128
< 900	256
< 950	512

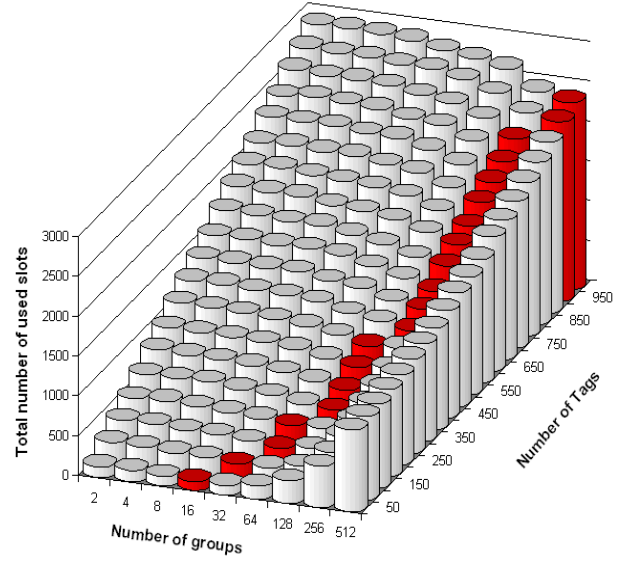


Fig.3: The number of used slots for different number of tags and groups.

4. SIMULATION RESULT

In this paper, we assume that the tag's ID number consists of 64 bits (all random bits). Our proposed method to estimate the total number of tags in the reader's field is efficient even though the number of tags is varying.

Note that we use the BT algorithm to identify tags in each group. Figure 3 shows the total number of used slots to identify all tags for different number of tags and groups, where the x-axis represents the number of groups, the y-axis indicates the number of tags, and the z-axis represents the number of used slots.

Practically, the less the number of used slots, the faster the algorithm. It is apparent that for a given number of tags, there is the suitable number of groups (i.e., the shaded columns) that yields the lowest number of used slots. Therefore, the proposed algorithm must first estimate the total number of tags in the reader's field so as to determine the suitable number of groups.

Figure 4 illustrates the estimated number of tags for different number of tags and groups, where the x-axis represents the number of groups, the y-axis in-

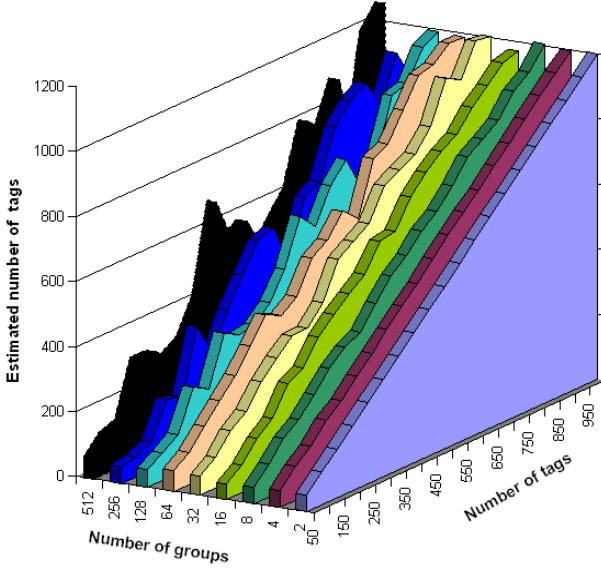


Fig.4: The estimated number of tags for different number of tags and groups (for $N_G=3$).

indicates the number of tags, and the z-axis represents the estimated number of tags. Clearly, the less number of groups will result in a better estimation of the total number of tags. For example, the number of groups of 2 will give 100% accuracy of the estimated total number of tags. However, based on exhaustive search, we found that the number of groups of 32 is the maximum number of groups, which yields minimum error of the estimation under specified condition. For example, for $N_G = 3$ and $N_{ALL} = 32$, the total number of tags from 0 to 200 tags will give an error of 31% – 37%, but for $N_G = 31$ and $N_{ALL} = 32$, the total number of tags from 0 to 200 tags will give an error of 0.05% – 0.15%. Thus, the chosen parameter for N_G will depend strongly on the error threshold requirement.

Figure 5 compares the percentage of error between the actual number of tags and the estimated number of tags obtained from our proposed method, where the x-axis represents the number of used groups for estimating tags, the number of used groups for estimating tags, the y-axis indicates the number of actual tags, and the z-axis represents the percentage of error. We first set the total number of groups of 32 (i.e., $N_{ALL} = 32$). Then, we vary the number of used groups from 1 to 32 (i.e., $N_G = 1$ to 32) so as to estimate the total number of tags in the reader's field. If we use a large number of used groups, the estimation error will be small, but the proposed algorithm will require a lot of number of used slots, which implies low efficiency. Conversely, if we use a small number of used groups, the estimation error will be large, resulting in unacceptable estimate. The percentage of error based on Fig. 5 can be set as a threshold to select a number of used group N_G or a sample size to estimate the total number of tags \hat{T}_{ALL} . When we set

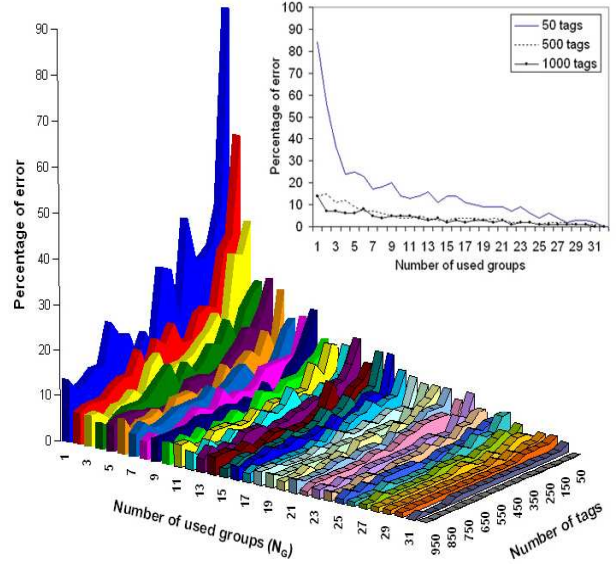


Fig.5: The percentage of error between the actual number of tags and the estimated number of tags (for $N_{ALL} = 32$).

the number of used groups to be $N_G = 3$, $N_{ALL} = 32$ as shown in our simulation result of Fig. 3 and Fig. 4, we realize that the percentage of error for 1000 tags maximum is less than 10%. If this is the error threshold requirement for identifying all tags, the algorithm will perform faster than chosen larger N_G and in turn using more time slots. If the larger number of used group N_G is utilized, the number of used slots will increase so much more that the advantage of error reduction will not be worth the effort.

In this paper, we compare the performance of the four algorithms, namely, Binary Tree, Binary Tree 3 bits, DFSA, and the proposed algorithm (with 32 groups), assuming that the tag's ID number consists of 64 bits (all random bits). Figure 6 illustrates the performance comparison as the plot between the number of tags (x-axis) and the total number of used slots (y-axis). The smaller the number of used slots, the faster the algorithm. The proposed algorithm outperforms the other algorithms, i.e., at the considering total number of used slots, the proposed algorithm uses a smaller number of tags. The advantage of the proposed algorithm is more visible as the increase of the number of tags and could be explained as follow. The DFSA divides groups of tags into slots randomly. Thus, tags are more likely to collide especially when a large number of tags are presented in the reader's field. While in the case of BT and BT 3-bit, the more numbers of tags presented in the reader's field, the more identical of the most significant bit ID of the tags. Therefore, more collisions occur resulting in higher used slots.

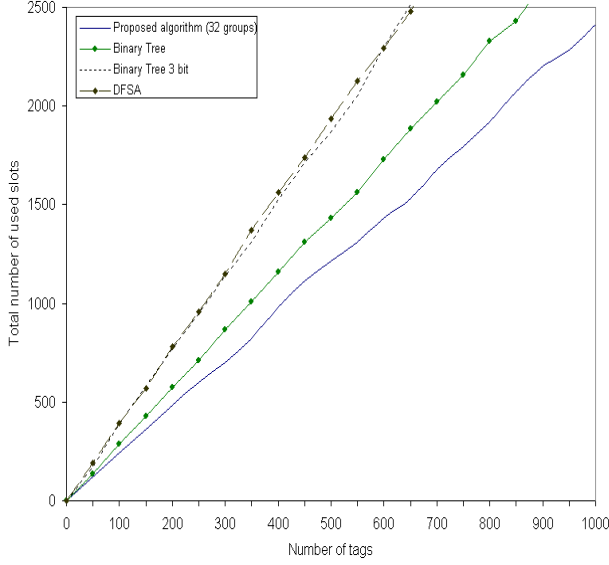


Fig.6: Performance comparison of different anti-collision algorithm.

5. COLLISION ANALYSIS

In this Section, we analyze the effect of data collision in RFID systems. Generally, the functionality of an anti-collision algorithm depends on data collision. For example, the DFSA algorithm uses the result of data collision in the slot to decide if the number of slots per frame should be adjusted, whereas the BT algorithm uses the result of tag responses to determine if the number of bits used to identify tags should be increased. Therefore, the result of data collision is of importance for anti-collision algorithms.

To perform the analysis, we create the RFID system in the hardware, where we use a front-end module from Austria-microsystems with an MSP430F156 microcontroller to control an RFID system. Figure 7 shows a system setup for our experiment, which employs an “as3990” chip controlled by a microcontroller. Practically, the as3990 chip will receive a command from a microcontroller that a reader wants to send to a tag. Then, this command is encoded and modulated before sending it to a tag. Whether or not the tag will response back to the reader depends on the tag’s working status at that time.

In general, one data packet that is transferred in an RFID system consists of two parts, namely, a preamble and a data. Therefore, the investigation of data collision in an RFID system can be preformed in two ways as follows:

5.1 By looking at a preamble portion

A preamble is at the beginning of a data packet, which is used to initiate the data transmission. If a data collision is occurred at this portion, the remaining data in that data packet will be lost. Thus, the reader cannot receive any data from the tags.

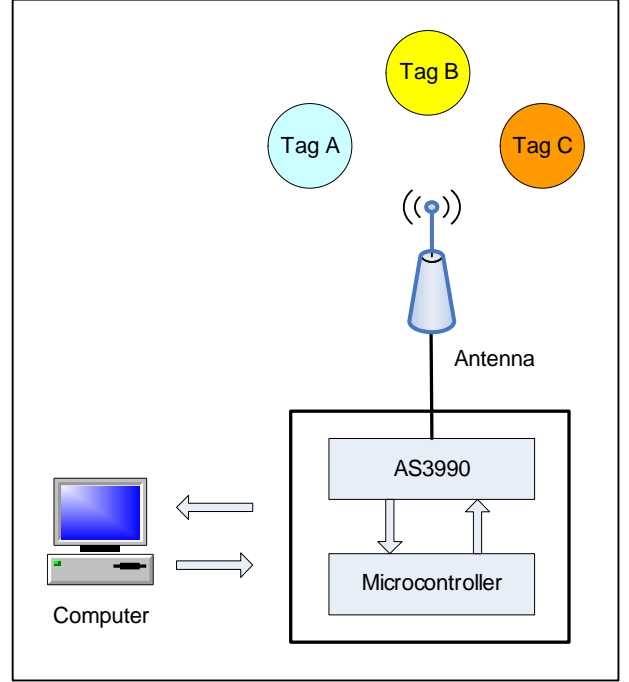


Fig.7: A system setup for our experiment.

5.2 By looking at a data portion

After a preamble can be detected correctly, the reader will begin receiving a data. However, if there is a collision occurred during receiving a data, the remaining data will also be lost. In this case, the reader can realize the damage of the received data by checking at a cyclic redundant code (CRC).

Figure 8 illustrates the signal that transmits and receives between a reader and a tag. The signal 1 and signal 2 are analog signals that the reader receives, while the signal D0 and D1 are digital signals. It is clear from Fig. 8 that there is no data collision occurred during data transmission between a reader and a tag. Conversely, Fig. 9 illustrates the data collision during data transmission. Specifically, there is a distortion in the analog signals, which causes an error in digital signals after modulation. This signal distortion can be obtained from many reasons, such as, the data collision from two tags, the interference from other signals using the same frequency, the reflection from signals, and noises/disturbances. As a consequence, we can classify the signal distortion into two main reasons, i.e.,

- 1) The signal distortion resulting from the two tags that send out the data to a reader simultaneously. This definitely causes a data collision. In this case, although the reader asks the tag to retransmit a data, the data collision is still occurred. To solve this problem, we need to increase the number of bits used to identify the tags in the BT algorithm, whereas the DFSA algorithm will skip this transmission slot and start a new transmission slot in a new frame.
- 2) The signal distortion resulting from noises. In this

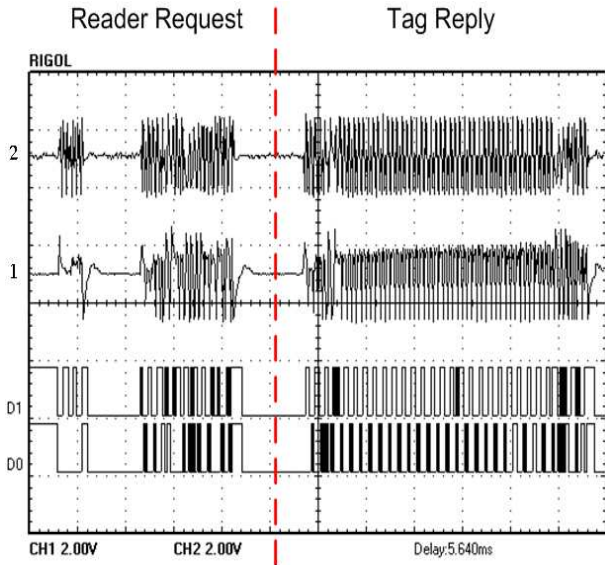


Fig.8: Analog and digital signals transmit and receive between a reader and a tag.

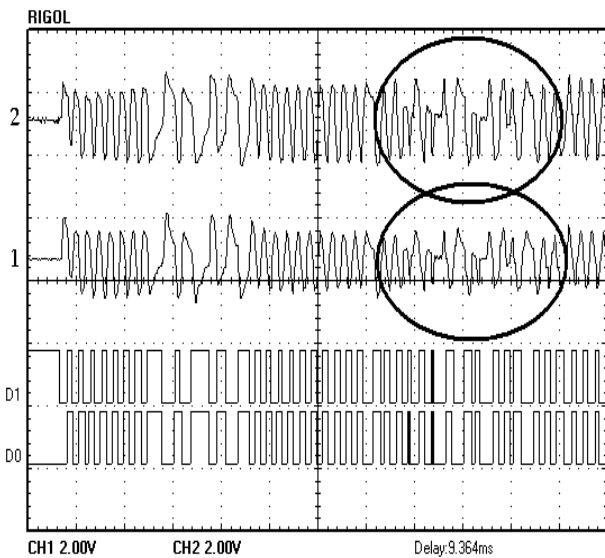


Fig.9: A response signal from the tag that experiences a data collision.

case, retransmitting a data from the tag to the reader might help solve the problem. This will reduce the time to identify the tags because we do not have to increase the number of bits in the BT algorithm and the DFSA algorithm does not need to skip the transmission slot.

Figure 10 shows the result of real testing in the hardware, which uses the BT algorithm according to ISO 18000-6 Type B. This figure is a plot between the number of tags (x-axis) and the total number of used slots (y-axis). The result of real testing coincides with that of simulation in the Fig. 6 in terms of linear relationship between the number of tags and the number of used slots. Consequently, we can iden-

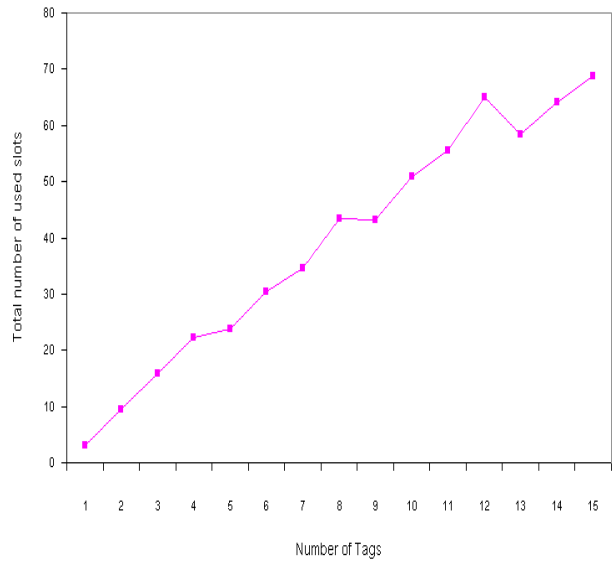


Fig.10: Performance of BT algorithm in real testing in hardware.

tify the number of transmission slots when we know the number of tags that follows a linear relationship according to Fig. 10.

6. CONCLUSION

The anti-collision algorithms are crucial to the application that uses a large number of tags. In general, the BT algorithm performs faster than the DFSA algorithm when the number of tags is small. The proposed algorithm exploits the advantage of both the BT and the DFSA algorithms. Specifically, all tags are divided into many groups based on the DFSA algorithm, and the tags in each group are identified using the BT algorithm. It is evident from simulation that the proposed anti-collision algorithm performs better than the existing ones in terms of the number of used time slots, which implies fast identification process.

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